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M. Takebayashi
Hitachi Tochigi Technology Co.

H. Hata
Hitachi Tochigi Technology Co.

T. Iizuka
Hitachi Tochigi Technology Co.

A. Ishiyama
Hitachi Tochigi Technology Co.

H. Kohsokabe
Hitachi Ltd.

A STUDY ON WEAR CHARACTERISTICS OF A ROLLING- PISTON-TYPE ROTARY COMPRESSOR

Masahiro Takebayashi, Dr., Hiroaki Hata,
Tadashi Iizuka, Akihiko Ishiyama
Hitachi Tochigi Technology Co., Ltd.

Hirokatsu Kohsokabe
Mechanical Engineering Research Laboratory, Hitachi, Ltd.

ABSTRACT

We have developed a useful means of estimating the wear rate in rolling piston-type rotary compressors. This method can accelerate the estimation of the wear rate of the vane and the piston about 65times as fast as conventional life tests operated continuously.

And this method was compared with the data of a component testing, obtained from a pin/block tester in a lubricant/refrigerant mixture. This method was clarified a practical accelerating rate compared with a conventional long-term life test on a benchtester.

This paper investigated effects of various lubricants and sliding materials on wear characteristics in a rolling-piston-type rotary compressor using HFCs through that developed method.

INTRDUCTION

Rolling-piston-type rotary compressors are widely used in air conditioners and refrigerators. They offer many advantages, including small size, light weight, simple structure and high performance. Reliability is one important factor for all kinds of compressors. But the behavior of a rolling piston in a rotary compressor is complicated. And this behavior changes according to many factors, such as operating speed, load, and lubricant viscosity. This piston and the vane rub each other in a relatively reciprocate motion in line contact. To date it has been difficult to confirm the reliability of the compressor in a short time.

We have developed a useful means of estimating the wear rate in rolling piston-type compressors. This method can accelerate the estimation of the wear rate of the vane and the piston about 65 times as fast as conventional life tests operated continuously.

SCHEMATIC OF THE NEW METHOD

Fig.1 shows the motion of a rolling piston in a rotary compressor compared with that in the test compressor used the new method. The contact area of the piston with a vane moves forward to the direction of revolution with partly reciprocating motion governed by the load, operating speed, viscosity of the lubricant and so on. The area of the reciprocating motion is under a very severe condition of lubrication because at the instance of the zero relative velocity, a lubricant film can not be formed and the friction heat can not be efficiently abandoned from the area. In our case, a piston rotates with partly reciprocating motion and after several 10 times of the reciprocating motion, the same area contact with a vane at the beginning comes to contact again. In the new method, the contact area on a piston with a vane is fixed in the same area because the reciprocating motion is restricted in the width that is 2 times of the crank eccentricity with using the Oldham's coupling. Fig. 2 shows more detail of the piston motion with restricted operation of Oldham's coupling. A rolling piston only revolves around the center of a cylinder and does not rotate itself. So the contact area where a piston and a vane slide each other in a reciprocating motion is restricted within a width of 2 times of the crank eccentricity. By using this method, the severe condition at the area of reciprocating motion can be efficiently accelerated not only in a mechanical state but also in a thermal state because the chance of friction heat abandoning is very much reduced. The accelerating rate in the case of rotary compressors we used for our product is estimated 65 times of a conventional continuously operated life test when simply considering the total sliding distance and load. We measured the numbers of rotation of a rolling piston in the actual compressor and the partly reciprocating motion occurs 65 times during a rolling piston rotates one whole round around its own center. It was calculated from the number of rotates measured. And much more accelerating rate is expected because the thermal damage is also accelerated in the way that chemical reactions related to lubricant and refrigerant can be easier occurred in the restricted area of the reciprocating motion. There is no chance to avoid contacting with a vane for restricted area and the temperature of the contact area goes up higher than that in an actual compressor.

EXPERIMENTAL RESULTS

(1) Test Equipment

Fig. 3 shows the structure of the accelerated testing compressor using the new method. With using the gap sensor and displacement transducer, the change of the wear depth can be monitored during the period of testing operation without disassemble. After the testing operation finished, the part of the rolling piston can be removed from the cylinder to check the wear depth. Also the lubricant used in the test was removed from the compressor and checked its typical characteristics for estimating the quality as lubricant.

Fig. 4 shows an example of the wear pattern on a piston after the test using the accelerated testing compressor. The wear width corresponds to the length of the reciprocating motion restricted by the Oldham's coupling. In this case, the test period was about 90 hours and the other conditions such as pressure, temperature, and operation speed are same as in the conventional overload long-term reliability test of 2000 hours or more. The wear depth in this example was approximately 60 μm and this amount of wear couldn't realized in a conventional long term test. So, it is obvious that this new method is effective for estimation of materials for rolling piston, vane and lubricant in short term.

(2) Estimation of Lubricants

Fig. 5 shows the experimental results of the accelerating test especially focused on the characteristics of lubricant. In this case, we used several kinds of ester to estimate them both in wear behavior and chemical stability:. The material used for piston was an improved casting iron, and that for vane was an improved powdered metal. The typical characteristics of each lubricant are shown in Table 1. The order of lubricants in the table corresponds to the order of lubricants estimated in the test. Ester I has a different type of alcohol and epoxy additive. Epoxy is used as the acid catcher for preventing the deterioration of lubricant with hydrolysis and the epoxy used in Ester I has comparatively higher ability of catching acid than that of the others. Ester III and IV have the same type of alcohol but different type of fat acid. Normal carbon acid n-Cn has straight chain type acid and has better lubricity but also has higher speed of moisture absorption. Each of ester II and V has different type of extreme pressure agent to increase the failure load in severe condition of lubrication. The above box of Fig. 5 is the comparison of the relative wear amount for each lubricant. The wear amount for Ester II is comparatively large, but for other esters, there is no remarkable difference. On the other hand, when considering about the change of the total acid number(TAN) shown in the box below, the TAN change for Ester II is especially large in comparison with the other esters. So, there is possibility that the chemical deterioration of the lubricant enhanced the wear amount in this case. Also, for Ester IV, the TAN change is comparatively large but the wear amount is small and this reason can be presumed that the epoxy additive works effectively and chemical deterioration doesn't enhanced the wear. For Ester V, the TAN decreased after the test and this reason can be presumed that the extreme pressure agent has characteristics to make the initial TAN higher and as a result of the consumption that to maintain the lubricity at the sliding surface of a piston, the TAN decreased and the wear amount didn't increase so much. Ester I and III have good result both in the wear amount and the change of TAN. Ester I has good chemical stability and effective epoxy additive, Ester II has good lubricity because it has n-Cn acid, so the wear amount is small in spite of the higher initial TAN.

*1) *Remark* : some of the Ester samples used for this estimation were on development and not final products when this test was carried out. Off course we can expect that they have been modified and the characteristics are much better now.

(3) Estimation of Materials for Rolling Piston and Vane

Fig. 6 shows the other experimental results. This time, the different material chosen for the piston and vane are estimated. All samples estimated with HFC134 refrigerant and Ester I lubricant. Sample A has the material used in the conventional CFC12 refrigeration system and the wear amount is comparatively large. This means that the lubricity in HFC134a system is much less than that in CFC12 system because chlorine in CFC has the characteristics to make thin oxidized iron film on a sliding surface and works as an extreme pressure agent. Each modified material used for Sample B, C, and D has good lubricity in HFC134a system. Each piston has the same modified cast iron which including newly added component to reduce corrosive wear. The vane material for sample B is modified alloy with powdered composite process. That for sample C is the same as sample B but added some surface treatment. Sample D has the different type of material for a vane, carbon-aluminum complex metal is used. The wear amount is larger than the other two samples especially in vane and the wear characteristic is also difference. Fig. 7 shows the gap sensor output and the total wear amount of piston and vane for Sample B and D. In the case of Sample B, the gap sensor output is coming stable in 40 or 50 hours after starting test. This means that the wear amount of a piston is not increasing remarkably and the state of wear becomes 'mild wear'. In the case of Sample D, The gap sensor output or the wear amount is going up steadily and the wear amount is larger in a vane. This is one of the feature of carbon-aluminum based complex metal(C/AL metal). The C/AL metal itself tends to wear comparatively easily but the damage for the material sliding each other is comparatively slight. There are several examples that the C/AL complex metal is used in actual rolling-piston type rotary compressors with HFC134a and ester lubricant.

COMPARISON WITH OTHER METHODS

There are several methods for estimation of wear with some accelerated conditions. FALX test using V-block and pin is one of the most general methods. Four-ball wear test has been used in many cases. Hitachi has developed the wear tester in high-pressure refrigerant atmosphere and this can be comparatively close to an actual condition. But in any cases, there is no consideration of the actual motion of the rolling piston in a rotary compressor because the motion is complicated and hard to realize artificially. In this new method, the behavior of a rolling piston and vane accelerated in the way of the actual behavior. The mechanical accelerated rate is several 10 times of the conventional overload life test because the Oldham coupling makes the reciprocating motion of a rolling piston concentrates to restricted area on the surface of a rolling piston. By using this method, the difference in wear characteristics of materials, lubricants, state of oil supply and other items can be found in comparatively short term. It is useful for estimation of rolling-piston type rotary compressor using new refrigerant and lubricant in the future.

CONCLUSIONS

The behavior of a rolling piston in a rotary compressor was analyzed and the new estimation method for wear characteristics with accelerated rate of piston motion has been established with making use of the Oldham coupling to realize the reciprocating motion of a piston concentrated to a restricted area. This new method can accelerate the reciprocating motion of a rolling piston several 10 times of the conventional overload life test mechanically. Also, the accelerated rate can be higher because the restricted area is less efficient for heat abandoning in comparison with the actual rotary compressor. By using this method, the difference of the wear characteristics between different kinds of lubricant, materials can be estimated in comparatively short term. It is useful for estimating the reliability of rolling-piston type rotary compressor with new refrigerants, lubricants and materials in the future.

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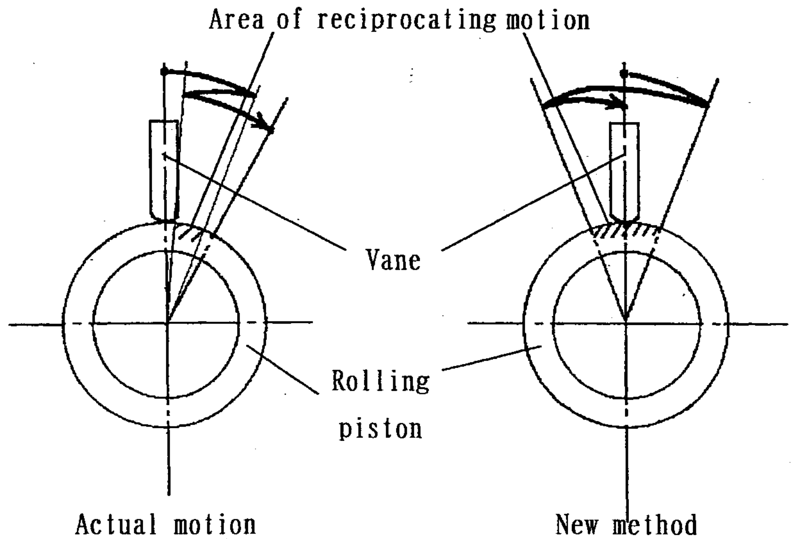

Fig. 1 Motion of rolling piston in actual compressor and new method

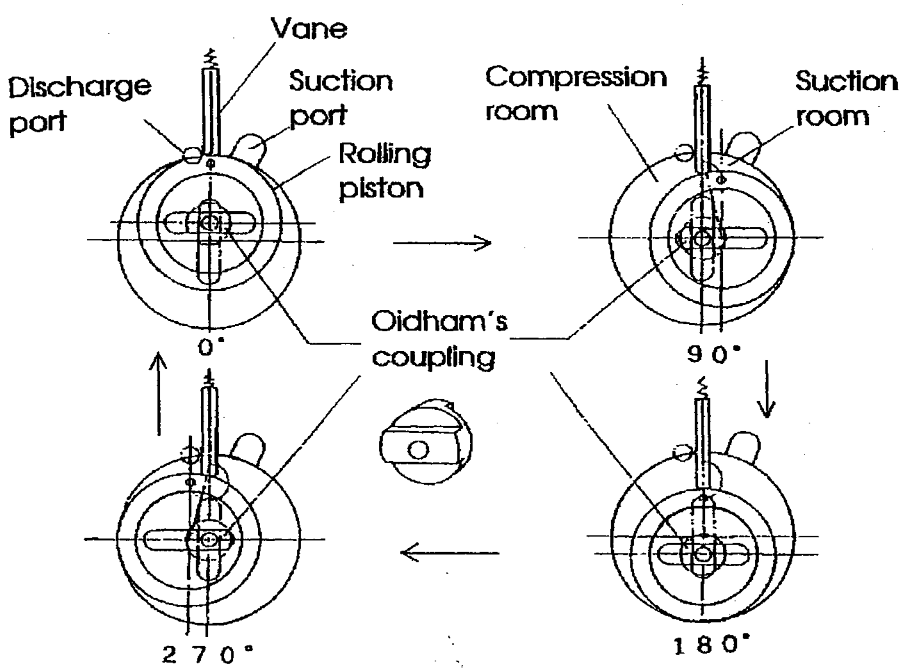

Fig. 2 Piston motion with restricted operation of Oldham's coupling

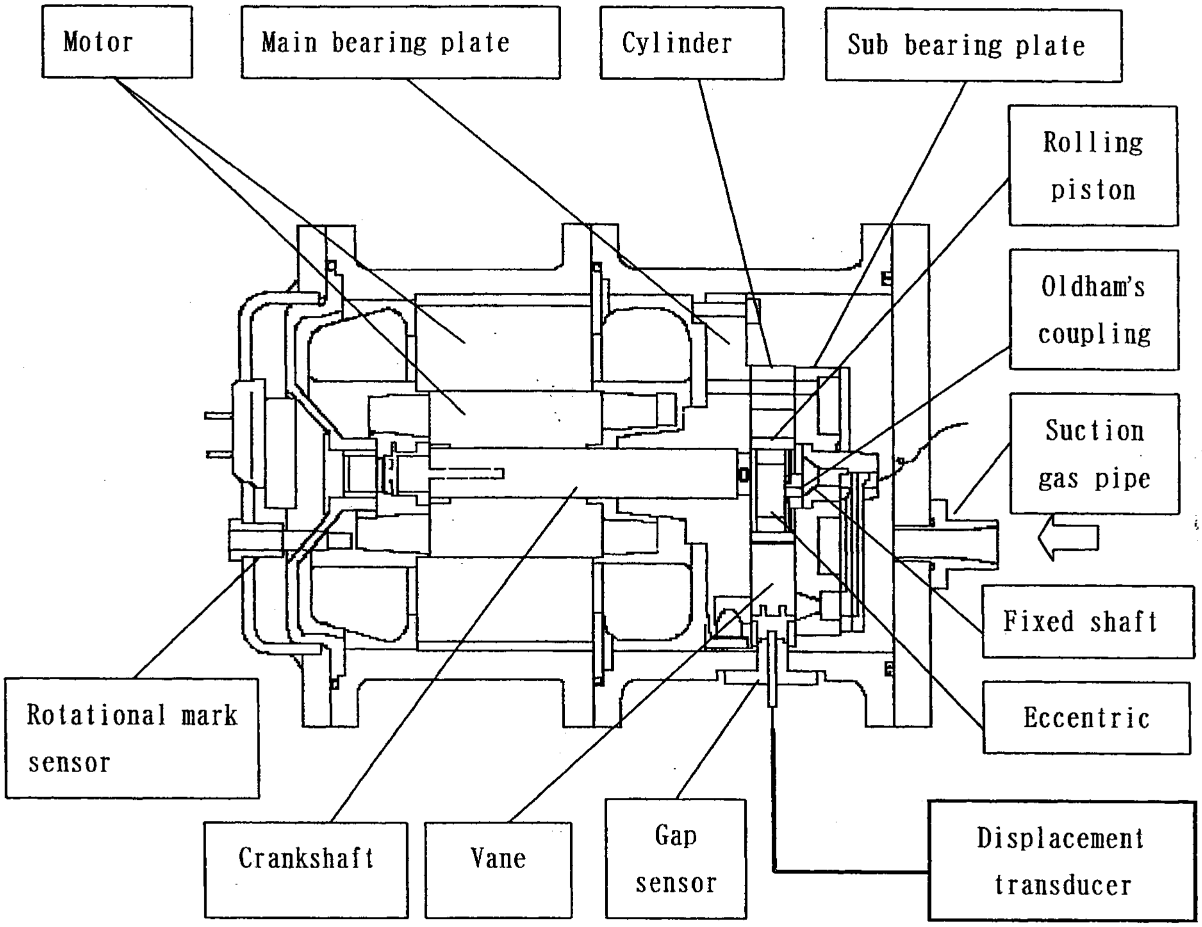

Fig. 3 Compressor for accelerated wear test

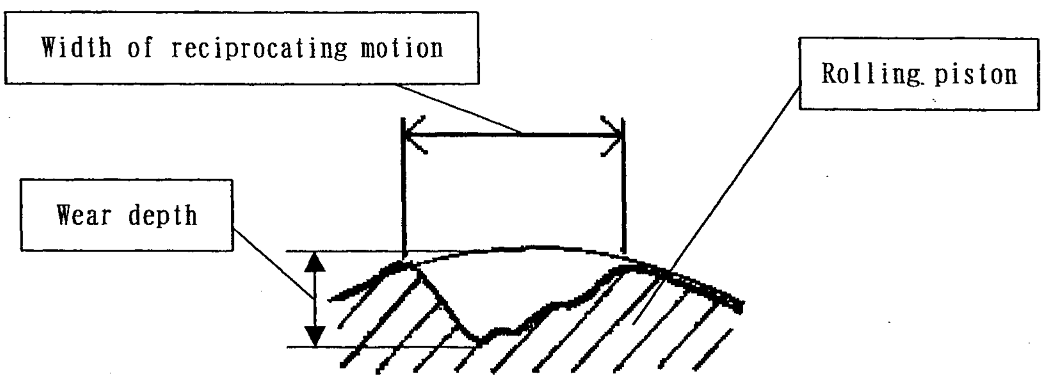

Fig. 4 Wear shape of a piston after accelerated test

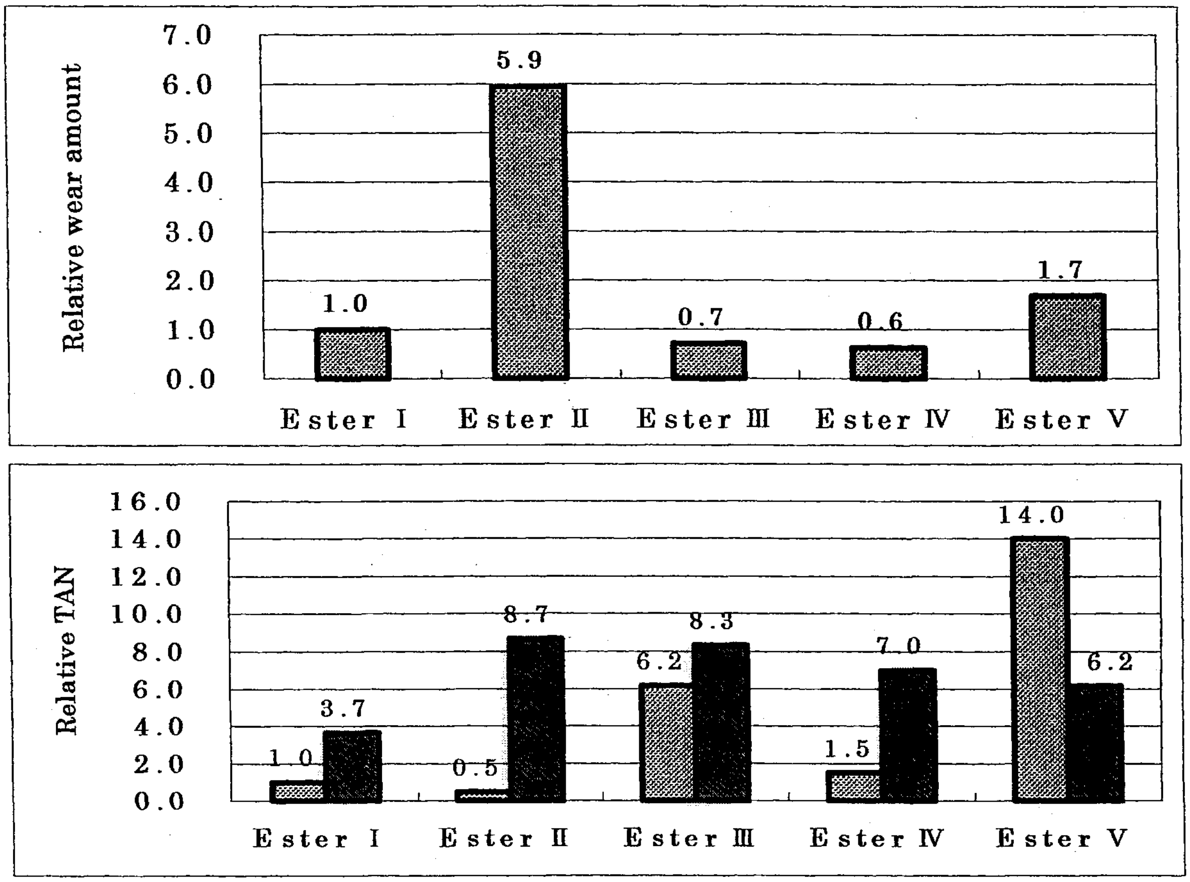

Fig. 5 Test result : comparison of ester lubricants

Table 1 Characteristics of Ester Lubricants

Lubricants	Ester I	Ester II	Ester III	Ester IV	Ester V
Alcohol Type	A	B, C	B	B	B
Acid Type	i-Cn	i-Cn	n-Cn, i-Cn	i-Cn	i-Cn
Additives	Epoxy A	Ex. Press. A	Epoxy B	Epoxy B	Ex. Press. B
	Antioxidant	Antihydrolysis	Antioxidant	Antioxidant	Antioxidant
Relative Failure Load: FALEX (%)	100	133	138	126	>185
Critical Soluble Temp. (℃)	-46	-56	-5	-35	<-60
Relative Initial TAN	1.0	0.5	6.2	1.5	14

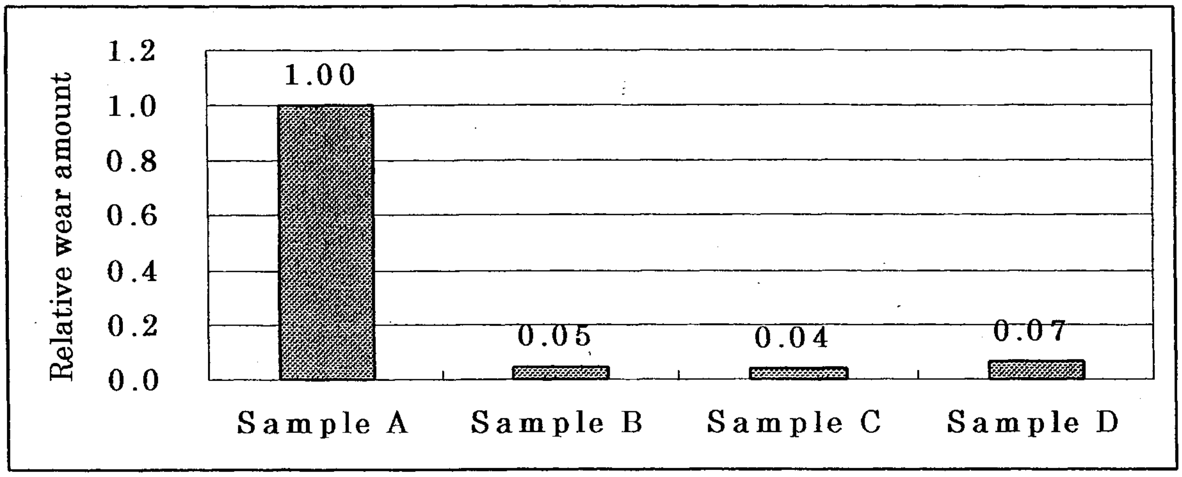

Fig.6 Test result : Comparison of sliding materials for piston and vane

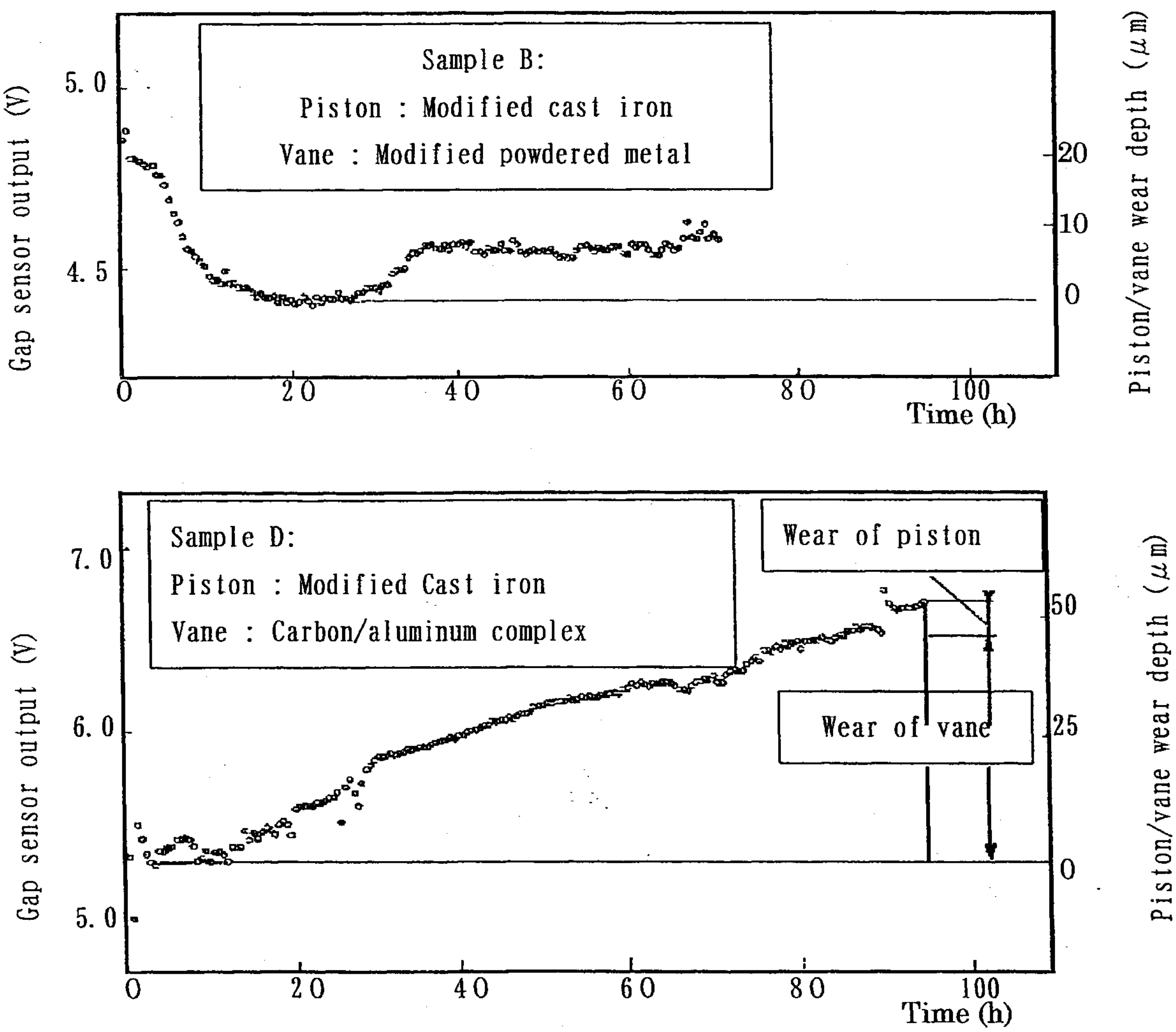

Fig. 7 Gap sensor out put for different materials